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THE RESEARCH POTENTIAL OF MANNED EARTH ORBITING SPACECRAFT IN THE FIELD OF METEOROLOGY

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Manned satellites can advance atmospheric science in a number of important ways. (1) Develop more rapidly and economically a refined system of electromagnetic sensing instrumentation which can be employed on future operational weather satellites. (2) Carry out specialized observing programs, e.g., in connection with earth-based storm modification experiments. (3) Perform a maintenance and repair function for the advanced weather satellites in a future operational system.

A human experimenter can make unique contributions in devising instrumentation to measure night-time cloud distribution, winds, temperatures, precipitation, water vapor and ozone content, cloud properties, aerosols, and the state of the sea, of snow, ice and terrain.

The economic value of an advanced weather satellite system in terms of improved weather forecasts is pointed out; it may also help solve scientific questions about the changes in climates.

Atmospheric Data: Why, What Kind, and How Much

The earth's atmosphere is a complicated physical system. We believe that we understand many of the physical laws which control what takes place in the atmosphere: the motions of air masses, the evaporation and condensation of water, even some of the microscopic processes in the formation of cloud droplets, and the less well-known problems of atmospheric electricity. Why then can we not predict the state of the atmosphere as easily as we can predict the occurrence of astronomical events?

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There is an important difference between a system such as the atmosphere and a system such as the planetary system. The latter is relatively simple. The motions of the planets are controlled by gravitational forces only, and because of the great distance between the planets, the interactions are basically between the sun and a single planet with any other effects entering in as minor perturbations. In the case of the planetary system, therefore, it is possible to perform one set of observations at a given time and then extrapolate or predict the motions of planets from then on. In principle the same procedure of numerical prediction is possible in the atmosphere, but in practice it is not.

The complication of atmospheric interactions is such that frequent observations are essential, and the predictions that can be made are good only for a very short time. Our aim, of course, is to increase the length of the prediction, and this problem of being able to predict the atmosphere is taken to be synonymous with our "understanding of the atmosphere." If we "understood" the atmosphere perfectly, then we should be able to take one set of observations at a particular time and from then on be able to predict the course of atmospheric processes, including all of the weather phenomena all over the globe.

More than any other science, meteorology relies on observations. Both the quality and the scale of these observations are important. By "quality" we mean the physical quantity which is being measured; i.e., the atmospheric pressure or the relative humidity, and the precision to which it is measured. By "scale" we understand the fineness with which these observations are carried out either on a horizontal scale, or on a vertical scale, or on a time scale.

A satellite can be considered as a meteorological observing tool par excellence, which surveys the whole globe daily. This time scale is adequate for most meteorological tasks; the horizontal scale can, in principle, be made as fine as necessary.

There is another parameter that one is usually interested in and that is cost. Meteorological observing systems are expensive to set up and expensive to maintain. Eventually when we have to make a decision about whether a satellite is a better way to observe the atmosphere, we must also consider the cost factor.

It has been adequately demonstrated that a satellite represents the most economical method for getting regular global data of a certain kind, e.g., the day-time cloud distribution. It is less well recognized that once improved instrumentation is available, much more data can be obtained at relatively little extra cost. An example, now within technical range, is an increase in horizontal resolution. Much more extensive development is required, however, before different types of observations can be perfected: the cloud distribution at night; the altitude and thickness of the cloud; its detailed properties; precipitation, etc.

The Advantages of a Manned Platform

It is the major contention of this essay that a manned space vehicle provides an economical method for investigating the limits to which satellite meteorology can be pushed. It is not intended that the manned orbital laboratory itself be an operational system for observing the weather routinely, but that it be used to advance the state of instrumentation of weather satellites by developing an elaborate system of sensors which could be used in unmanned meteorological observational platforms of the future, as the second or third generation of today's meteorological satellite system.

It should be noted that the man is not used as the operational observer; that is left to instruments. His function is three-fold: 1) to act as the experimenter in developing efficiently some very advanced instrumentation; 2) to be used for specialized non-routine types of observations (e.g., during storm modification experiments); 3) to maintain or repair instruments in an elaborate meteorological observatory of the future.

The use of a man, rather than a robot, in all of these operations must be established on the basis of cost. It can be shown quite directly that as complexity increases reliability of operation must be purchased at an ever increasing cost. Beyond a certain level of complexity the use of a man becomes almost mandatory, not only in space, but in an earth-bound operation also.

Scientifically, the manned platform is desirable because the basic problem of atmospheric observations is such that one cannot predict in advance the exact details of instrumentation which will allow the most beneficial types of observations; i.e., even today it is quite difficult to decide such broad questions as the use of infrared versus microwave sensors for measuring the vertical temperature structure of the atmosphere, and indeed no final decision has as yet been made. Further than that, however, such details as the setting of the exact wavelength, the width of wavelength intervals, and the effects of various atmospheric conditions on the observations cannot be gauged sufficiently well in advance.

Some reflection will show that it is too expensive to develop the necessary instrumentation in unmanned flights, and too time consuming. The reason, of course, is that these unmanned flights would have to be successive so that each one could take advantage of the results of the preceding flight. Such a program extending over a ten-year period would certainly run in excess of 200 million dollars. Yet within this period we will surely have available manned platforms which can carry out the necessary experiments with much less effort, at a much smaller cost, and much sooner.

The economic argument is simple. Orbiting manned platforms will be launched in the near future. It is clear, therefore, that one should not assign all of the cost or even a major fraction towards its meteorological application. It is suggested, therefore, that a proper cost comparison should use an incremental cost of the manned program, and in addition assign a value to time gained in the development of instrumentation through the use of experiments on manned platforms.

From experiments on manned platforms an ultimate unmanned weather satellite system could be designed which will allow us to obtain the optimum operational data needed for long-range weather prediction and for the many other tasks which weather satellites are capable of doing.

What then are these various types of measurements? Rather than prepare an exhaustive list, we propose to discuss here those measurements which have important meteorological and other economic applications while at the same time being challenging from a scientific point of view. We will discuss the use of satellites for establishing the cloud distribution by day and by night, for measuring winds at various atmospheric levels, for determining the vertical distribution of temperature in the atmosphere, for measuring the existence and amount of precipitation and water vapor content, for measuring cloud altitudes and cloud properties, for the determination of aerosols and other particulate matter in the atmosphere, for the determination of the overall radiation and energy balance, and for such measurements as sea state, snow cover, and ice distribution. Finally also, we discuss the measurement of atmospheric composition, especially the three-dimensional distribution of ozone.

An effort will be made to introduce into this essay new ideas, some of which have not been discussed previously in the literature. Partly this is because such measurements were thought to be not feasible; however, a manned platform allows us to carry rather elaborate instrumentation, and large weight and power requirements pose no particular practical problem. This feature has a very important consequence which cannot be overemphasized. It allows us to fly and operate a number of experiments simultaneously and use their combined results for drawing conclusions about the atmosphere. The atmosphere is a very complicated system; often to obtain an answer the same question must be asked in a number of different ways.

By contrast, in most unmanned satellites payload space is extremely limited both in terms of weight and power, so that each satellite can only carry one major experiment. As we shall see, the possibility of making measurements with different types of apparatus allows one to obtain a great deal more insight into atmospheric phenomena. And, of course, the presence of a man who is able to make adjustments to the apparatus in the light of the results obtained either through his own intelligence or following the instructions of a ground-based scientific control group can make such an effort much more worthwhile, at a great saving of money and time.

Sensing by Electromagnetic Radiation

Before we undertake a detailed examination of the various atmospheric parameters which can be measured by satellites, it is important to examine how a satellite senses the atmosphere. Naturally, a satellite does not make physical contact with the atmosphere; therefore, it cannot use conventional measuring devices such as thermometers, pressure gauges, humidity sensors, etc. Instead it must relay exclusively on electromagnetic radiation which reaches the satellite sensors from the earth's atmosphere below.

All of the electromagnetic spectrum is available but not all portions are equally useful. By and large it makes sense to consider four main wavelength regions: the ultraviolet - from about 2500 to 3200 A; the visible and near infrared from about 5000 to 20,000 A; all of the infrared from about 2 micron on up to 30 micron; and the microwave region from a few mm to about 30 cm.

A different type of classification is useful, according to the ultimate source of the radiation: 1) Scattered or reflected radiation whose ultimate source is the sun or perhaps an artificial source carried aboard the satellite; i.e., a laser or a radar transmitter. 2) Emitted radiation which originates in the atmosphere, or from clouds in the atmosphere, or perhaps from the earth's surface.

Most useful so far has been scattered solar radiation in the visible region which has been used for the TV coverage of cloud patterns and details of the earth's surface. The other important region has been the infrared radiation emitted by the atmosphere, by clouds, and by the earth's surface which has allowed us to determine the temperatures of these three sources.

Night-Time Cloud Distribution

A good example of an important experimental task which cannot be laboratory simulated and which is therefore best relegated to an actual experiment in a manned spacecraft, is the design of a television system for night-time operation under very low light levels. It is necessary to use devices which are much more sensitive than the vidicon. For example, image orthicons have been suggested and other more experimental devices. All of these require fairly careful adjustment and tuning, which can be supplied by a man.

But in addition to this, the effects of background radiations such as the airglow cannot be assessed in advance. The problem is one of trying to obtain the greatest contrast between clouds and the earth's surface, and simultaneous elimination of the airglow from starlight, from zodiacal light, and perhaps from a little moonlight.

Different studies have come up with different results; however, a man could be in a position to determine which portions of the electromagnetic spectrum to use in order to eliminate the interfering effects of the airglow and other background emission.

Winds

Unfortunately, direct measurements of winds from satellites is difficult, if not impossible. One can conceive of a technique for detecting scattered radiation which is slightly Doppler shifted because of the velocity of the scatterer; but a simple calculation of the magnitude of the shift will convince one that the effect is hardly observable. It is necessary, therefore, to measure winds by tracking something which is carried in the atmosphere. This "something" can either be a natural particle, perhaps a collection of particles constituting a cloud, or it can be a body artificially placed into the atmosphere, such as a puff of smoke or a floating balloon.

Clouds have the advantage of being available at no cost, but their availability can never be assured. In addition, many clouds do not move with the velocity of the wind; some do not move at all. Great care must be taken before a cloud can be used as a reliable wind indicator. Artificially introduced particles are usually transitory and have to be replaced. If winds have to be measured at several vertical levels and at many locations all over the earth, the number of floating balloons which has to be introduced can become quite large, raising the costs of such a system to a level where its practicality has to be scrutinized very closely.

Much more work needs to be done to recognize the natural particles which can give information about atmospheric motions. It is doubtful whether this can be accomplished simply by taking television pictures of clouds. A manned vehicle has the advantage that the particles can be studied more carefully by examining the "cloud" at various magnifications by noting their altitude, by studying if necessary the size distribution of the particles, and other important properties.

Even if the cloud method for tracing winds does not become of general operational significance, such studies will enhance our general knowledge about the motion of clouds in the atmosphere and contribute, therefore, in an important way to our understanding of atmospheric processes.

Temperature Structure

Far more adaptable to satellite techniques is the determination of the vertical temperature structure of the atmosphere. The method, originally suggested by Lewis Kaplan, is by now well known. It makes use of the fact that CO_2 has strong absorption bands in the infrared. By observing the energy received at a number of wavelengths near 15 micron, one can determine the effective temperature of a number of diffused levels in the atmosphere.

A theoretical study would indicate that the method is most applicable above about 10 km. If one chooses wavelengths which allow contributions from very much lower altitudes, one also receives contributions from the surface which are not so easily evaluated. And worse still, one sees contributions from low-lying clouds, aerosols, etc., which are not taken into account in the calculations which refer to a clear atmosphere.

In fact, it is not possible to evaluate the effectiveness of the infrared method just described until extensive experiments have been undertaken. These must be carried out from at least balloon altitudes and should cover a variety of meteorological situations, as well as different latitudes and, ideally, different seasons.

In order to evaluate the method it would be essential to have an instrumentation which is much more elaborate than the one which is now being built for unmanned weather satellites. The latter observe at only six wavelengths but in a manned vehicle a more elaborate setup could be accomodated, covering the 15 micron band at many more wavelengths and covering other absorption bands as well for the sake of comparison. (It may be expected that the contribution of aerosols is different at 15 micron than it would be at other wavelengths since the size of the aerosol particles plays a determining role in their effectiveness for radiation emission.)

A very important question which can only be settled properly by direct experiments is the comparison of the CO_2 15 micron experiment with a corresponding one in the microwave region based on the absorption properties of molecular oxygen. In the microwave region, the disturbing effects of aerosols and even of clouds are much less pronounced; on the other hand, the effects of the surface become more uncertain.

It turns out that the technical realization of the microwave experiment is quite difficult. It requires very low noise receivers which cannot as yet be accomodated within the limited payload and power capability of unmanned weather satellites. Presumably, however, in a manned space station this difficulty would not exist and, therefore, it would be possible to conduct a simultaneous comparison of the infrared and microwave experiments.

Water Vapor

The vertical distribution of water vapor can in principle be obtained by measuring either its infrared or microwave emission at a number of convenient wavelengths in the absorption bands of water vapor. The result gives the temperature corresponding to a certain pressure depth of water vapor. But if the temperature-altitude curve is independently measured as just discussed above, then one obtains the pressure of water vapor at various levels in the atmosphere and, therefore, its vertical distribution. Only very crude experiments have been carried out in Tiros satellites but they indicate that the method is feasible, at least in principle. Its ultimate accuracy, which will be short of what is possible theoretically, cannot be assessed again until actual experiments are carried out. In order to choose the proper wavelengths for observations, quite protracted experiments will be necessary, either from balloons or from manned satellites, involving an examination of all of the likely absorption bands of water vapor in the infrared and microwave regions to determine which one or which combination of bands is best suited to give the highest accuracy.

Again, a manned satellite vehicle has the great advantage of allowing perfectly controlled adjustment of the equipment.

Radiation and Heat Balance

The overall energy balance of the atmosphere can be obtained quite directly from satellites. The satellite can measure to any detail desired the radiation emitted from the earth below without distinction as to where it originates, whether at the surface, in the atmosphere, or from clouds, and it can also measure the total of the solar radiation which is scattered back by the atmosphere or reflected from clouds or from the surface. Such measurements have already been carried out, albeit crudely, from the Tiros satellite. However, it remains for meteorologists to devise methods for utilizing this information effectively in numerical predictions of long-term weather changes.

Surface Emissivity

Reference has been made from time to time to the infrared and microwave emission from the earth's surface. This emission is not at all well known. It clearly depends upon temperature and emissivity; the latter depends on the state of the surface, whether it is a land surface or an ocean surface, whether it is covered with snow or ice. (It even depends on the state of the ocean and, therefore, may give a useful way of measuring sea state.)

Indications are that the infrared emissivity of the surface is high but not quite equal to one and that it drops off towards lower values in the microwave region, especially for ocean surfaces which have very low emissivities. This means that in the microwave region an ocean surface will emit very little radiation and, therefore, appear to be quite cold to a microwave radiometer. On the other hand, the ocean surface reflects any radiation which falls upon it from above. In a wavelength region where the atmosphere is completely transparent and has no absorption bands and therefore no emission, the ocean surface simply reflects the microwave noise which is incident from extraterrestrial sources. However, as we move into the wings of the atmospheric absorption bands, the ocean surface will appear to warm up; and with a disturbed ocean surface where the atmosphere is viewed at larger zenith angles, the effective temperature would increase considerably. Therefore, it is possible in principle to measure the sea state by determining the emitted microwave power at certain wavelengths.

This is a passive method for measuring sea state. An active method depends on reflected solar radiation-sun glint. Sun glint has been noted in many satellite pictures and the size of the sun glint area gives a fairly direct indication of the smoothness of the ocean surface. Work is now underway to provide a more quantitative relationship.

In principle, the state of the ocean surface could also be investigated again by artificial light sources; i.e., by lasers. A smooth ocean surface will give specular reflection to an incident laser beam. A disturbed ocean surface will scatter the beam. It appears to be possible to devise a satellite experiment which can take advantage of this phenomenon, but the technique would have to be tested carefully.

The peculiar property of low emissivity of the ocean surface in the microwave region can also be used to detect and measure precipitation over the oceans. Essentially, as suggested by K. Buettner, the collection of water droplets will appear to be a warm spot superimposed over a "cold" ocean surface. Again, many experiments will have to be undertaken before effective use can be made of this phenomenon; but in principle it appears possible. It would allow us to study the important process of energy exchange between the atmosphere and oceans which usually escapes detection.

The combination of infrared and microwave techniques can be exploited further for more detailed examination of the earth's surface. For example, it has been suggested repeatedly that the thickness and water content of snow cover could be estimated in this manner, as well as the thickness of sea ice and perhaps its closeness to breakup. Again, experiments are lacking; some of these can be carried out from platforms at rather low altitudes, from aircraft and from blimps, before a satellite experiment is designed. Unmanned weather satellites do not constitute the most efficient way of testing the basic parameters of such an experiment. On the other hand, manned satellites which carry elaborate infrared and microwave instrumentation can easily investigage these parameters by simply changing the wavelengths to a region in which the atmosphere does not absorb and in which the surface, therefore, becomes visible.

Active Radar Experiments

There has been a good deal of discussion, both pro and con, concerning the advantages of an active radar in weather satellites. The most common objective has been directed to the detection of droplets and precipitation - somewhat in the manner of a ground-based weather radar. However, active radar in satellites may be better suited to quasi-meteorological applications: determinations of sea state, snow and ice characteristics, and terrain properties. In distinction to passive microwaves (discussed above), one would be concerned here with measuring a reflection coefficient, and perhaps polarization, rather than thermal emission.

A manned experimenter would be in a good position to use the radar (or radars) selectively, directing it against specific ground targets, varying the power, pulse width, and especially the frequency, to take advantage of the prevalent meteorological situation.

Sferics

Thunderstorm detection by the emission of radio noise bursts ("sferics") seems to be suitable for satellites. Again, an experiment must be performed to arrive at an optimum setting of frequency, bandwidth, sensitivity, etc. - to detect what is best adaptable to meteorological use and to avoid man-made interference.

Analysis of Cloud Tops

One of the most important areas for measurement available to a satellite is the detailed investigation of the tops of clouds including the determination of cloud temperature, cloud altitude, and size distribution of cloud particles.

The cloud altitude in terms of pressure can be measured by using the cloud as a reflector and determining the thickness or depth of overlying atmosphere, according to the proposal of Hanel, Wark, and Yamamoto. Use can be made of the absorption bands of molecular oxygen, particularly those in the vicinity of 7600 A. In the present proposal, the sun is used as a source. However, it may be entirely feasible to use a laser operating at the proper wavelength.

In fact, since the wavelength of a laser can be varied under certain circumstances, it is possible to investigate the region in the band and near the band; the ratio between the two establishes the absorption due to the oxygen and, therefore, the cloud altitude (in terms of pressure).

In this determination, the assumption is made that the cloud is an adequate reflector. This point can be checked, however, by using a pulsed laser and determining the travel time. This direct measurement gives us cloud altitude in geometric terms; i.e., the actual distance of the cloud top from the satellite. It also allows us to establish the time spent by the light pulse in the cloud's interior before re-emerging.

A further approach is the measurement of the infrared emission from the cloud top which is a measure of temperature.

The three measurements together thus establish the actual height in the atmosphere, and the temperature and pressure at that point. It is clear that such measurements are possible whenever there exists an adequate reflector; e.g., a cloud.

In principle this method could be used to measure the pressure at sea level, in the absence of clouds. However, it is very likely that the accuracy will be so poor as to make such measurements meaningless. Nevertheless it is important to carry on appropriate experiments. Because of the complicated absorption structure of oxygen, it will be necessary to carry out such experiments with a great deal of refinement of technique, again requiring bulky apparatus which is most suitable to a manned orbiting laboratory.

It is important to note that the cloud top measurements just described can be carried on at night if a laser is used, so that the method has quite general applicability.

The properties of the cloud particles can be investigated in detail by studying the reflection properties of sunlight or of laser-produced light. The reflectivity at different wavelengths can be related to a size distribution of particles. The important region here extends into the near infrared and as far out as perhaps 4 to 5 micron. As strong laser sources become available at longer wavelengths, such sounding techniques will become feasible, as indeed they are in the microwave region where weather radar is used to determine the existence of water droplets.

Ozone Distribution

Since ozone absorbs strongly in the region between 2500 and 3000 A, it is possible to establish its distribution in the stratosphere by measuring the amount of backscattered radiation in this wavelength region. Solar radiation has commonly been suggested. However, the method can be extended by using the moon as a source or even starlight, so that in principle a day and night method exists for measuring ozone distribution. No experiments of this type have as yet been carried out from a satellite although some rocket surveys of scattered ultraviolet radiation have been performed.

Again, it will be desirable to carry out the initial experiments with elaborate instrumentation having large light-gathering power and extremely high resolution, in order to establish the best operating conditions for an eventual unmanned experiment. Furthermore, there is likely to be interference to the ozone measurements arising from the existence of high altitude cirrus clouds. In order to establish their existence, one might want to use a laser detection technique so that a diagnostic service would be provided to explain any unusual results of the ozone instrument.

Conclusion

It is quite clear that what is needed in order to design suitable instrumentation for studying the atmosphere on a routine basis is a veritable meteorological observatory carrying at the same time all kinds of instruments having the highest possible resolution, light-gathering power, and flexibility in wavelength setting, etc., in order to provide data which give complementary information. This feature, more than anything else, may explain the immense usefulness of a large manned space station for meteorological research.

It is one of the characteristics of the atmosphere, which is a very complicated system, that one has to ask the same question in a number of different ways. One, therefore, has to build constructive redundancy into the instrumentation. An example is the temperature structure of the atmosphere. It may have to be measured in the 15 micron bands of carbon dioxide as well as in the microwave region absorption of molecular oxygen, or perhaps in other ways. The point is that all of these methods must be tested our simultaneously in order to be able to get a cross-check. There are different disturbing effects which enter in, for example, high cirrus clouds would affect the infrared but probably not the microwave. On the other hand, the contribution from emission from the surface of the earth will affect the microwave region in a more uncertain manner than the infrared. It is clear, therefore, that many of these problems can only be settled by direct test. A manned platform has the advantage of allowing a large weight and power capability and, therefore, makes it possible to fly several experiments at the same time. In addition, the presence of the man introduces great simplifications in the design of the equipment. It eliminates the need for many items which would have to be included in an unmanned experiment.

It proves the old statement: "Man is the lowest cost 150-pound non-linear all-purpose computing system which can be mass-produced by unskilled labor."

In justifying at least part of the manned program for atmospheric science studies one has to grant several assumptions. First and foremost is the assumption that we are willing to improve meteorological satellite instrumentation and are willing to spend money on this. This assumption can, of course, be defended on the grounds that the improved information about the atmosphere leads to the possibility of making improved forecasts of weather, of climate changes, and to the fundamental scientific basis for weather and climate modification. The economic value of all of these possibilities is well appreciated, although it has not been detailed sufficiently well.

At this point, it might be appropriate to consider some of the real benefits to be derived from such research. Economic estimates of improved weather forecasting have been made many times and these estimates predict savings of the order of billions of dollars to our economy arising from improved forecasting over a period of only a few days. Of more basic scientific importance is our understanding of the behavior of the atmosphere over longer periods and of understanding the causes for climatic changes.

Scientific Questions for the Future

Satellites give us a method of continuous surveillance of the earth's atmosphere. We can observe global changes with much greater sensitivity than any previous method at our disposal. We should be able, therefore, to study perturbations of the climate produced, for example, by volcanic eruptions which put a great amount of dust into the atmosphere. We should be able to study perturbations produced by large solar outbursts which have pronounced effects on the upper atmosphere and perhaps some effects on the lower atmosphere as well.

It is generally believed that the ozone is a more sensitive indicator to solar effects than any other meteorological parameter. To what extent is the ozone distribution responsible for climatic changes and to what is it a consequence of climatic changes? To what extent is the climate controlled by ocean temperatures and ocean currents, by global snow cover, by the extent of the ice cap in the polar regions, and by long-term variations of world cloudiness?

We may even be able to answer some rather fundamental questions. For example, is the present climate of the earth the only one possible considering the earth's environment, composition of atmosphere, state of surface? What happens when external factors perturb the climate? Does it return to its original base value? Are there discrete levels in the climate? Or is it possible to speak about a continuously varying climate?

The answers will not be known for some time but a beginning is being made in our search to understand one of the most important problems facing man in his environment on this planet.

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Bibliography

For a concise discussion of the four basic approaches to weather prediction (analog, statistical, physical, numberical) see; e.g., M. Tepper, "Meteorological Satellites" in Space Exploration, McGraw Hill, New York 1964

A detailed discussion of problems relating to meteorological satellites is given in the April 1963 issue of Astronautics and Aerospace Engineering. See also the book by K. Y. Kondratiev Meteorological Satellites (in Russian), available in English as NASA Technical Translation TT-F177 (May 1964) from OTS, Washington.

Atmospheric optics and radiation are discussed in the February 1964 issue of Applied Optics, and in the book by R. M. Goody Atmospheric Radiation (Oxford 1964).

TABLE I ELECTROMAGNETIC SENSING OF THE EARTH FROM SATELLITES

	Ultraviolet (0.2-0.32μ)	Visible and Near Infrared (.5 - 2μ)	Infrared (2 - 30μ)	Microwave (0.5-30 cm)	VHF (~1 m)
Active (Scattered or reflected) (Source may be the sun, or moon; starlight or air-glow; or an artificial source such as an optical or IR laser or microwave trans-mitter)	Ozone distribution	Cloud distribution Cloud top altitude (pressure) Cloud properties Surface properties (terrain, sea state, ice, snow)	Aerosols and particulate matter	Surface properties	
Passive (Emitted)	(Airglow)	(Airglow)	Temperature structure Surface temperature Cloud top altitude (temperature)	Temperature structure Water vapor distribution Surface properties	Sferics

TABLE II

Desirable Characteristics of Manned Satellite Laboratory

Orbit:	
Altitude	200 n. mi.
Inclination	highest obtainable
Duration	30 - 60 days
Spacecraft:	
Resupply	not needed
Volume for Experiments	500 $ft.^3$
Weight for Experiments	2000 lbs.
Power for Experiments	2 kw
Peak Power	5 kw for 1 hr.
Stabilization Capability	within 1° of vertical